The Monitoring of Fast Progressive Landslide Movements in Taşkent/Konya via Rapid Static GNSS Techniques

Mustafa ZEYBEK, İsmail ŞANLIOĞLU, Adnan ÖZDEMİR and

Temel BAYRAK, Turkey

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SUMMARY

Landslides, which leave deep scars in the topography and occur quite fast in a short time, are one of the most dangerous types of natural disasters. Therefore many methods have been developed for the monitoring of landslides. The technique of GNSS is one of the most widely used techniques for the prediction of landslides. In this study scope was covers GNSS works on the progressive Taşkent / Konya landslide. This study site was chosen as a result of the landslide that destroyed the Balcılar road, which provided transportation in the Taşkent province between the other towns and villages in the Tashkent district. Recently, due to the impact of global warming, the sudden and excessive rains trigger landslides in this region.

However, the landslide size had been determined by coordinate changes which were obtained by means of the rapid static GNSS method and with the help of statistical algorithms that had been used for fast analysis. The field studies, which were conducted three different times in 2010, had been evaluated. According to the results of this analysis over 1m landslide movements were determined. Thus, revealing that we are able to provide the time to take the necessary precautions so that landslide damage can be prevented.

In this paper, the data acquisition, analysis of data, and evaluation of the process's stages are presented. As a result, we'll show that GPS techniques are reliable, inexpensive and a good technique that enables high accuracy in predicting fast and constantly moving landslides.

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1. INTRODUCTION

The most important aim of the field of landslide study is to reduce damage and prevent disasters. Landslide research is a very common topic in literature. Fatalaties in landslide risk zones are very rare and very seldom. However, large and rapid progressive landslides results are very serious (Blasio, 2011). Even if the death ratios are small, landslide damage can result in many different areas in inhabited regions, such as roads, property, topography, water channels, pipelines and drainage channel networks.

Landslides are a topic for research in many countries. Landslide disasters occur almost worldwide, from high mountain areas to coastal areas and even in marine geologic units, from very wet or heavy rainfall areas to very dry areas, and from seismic or volcanic areas to tectonically non-active areas (Sassa, 2007).

In periodic monitoring of landslides by GNSS, a geodetic network proficient at predicting landslide movement is based on applicable stations on hills to be monitored.

This study adopted the landslide area as its study area and used a Rapid Static GNSS system to predict and monitor landslide movement as well as post-processing statistical analysis.

2. STUDY AREA AND DEFORMATION NETWORK

The study area is located in the east of Taşkent Town in the south of Turkey (Figure 1). The area is very rough and steep. The landslides in that region are generally classified as rotational and translational. The flow direction of the landslide is toward the river Sazak. Landslide area is affected by rainfall and underground waters usually with seasonal rainfall affecting the size of the landslide. The study area covers approximately 40 ha. In the study area, roads, property, forest, pipeline, irrigation channels, and drainage channels receive damage from landslides every rainy season.

For the purpose of this study, the movements of landslides are predicted with geodetic monitoring network. The network includes reference points and rover points for giving a choice between moving and stable points.

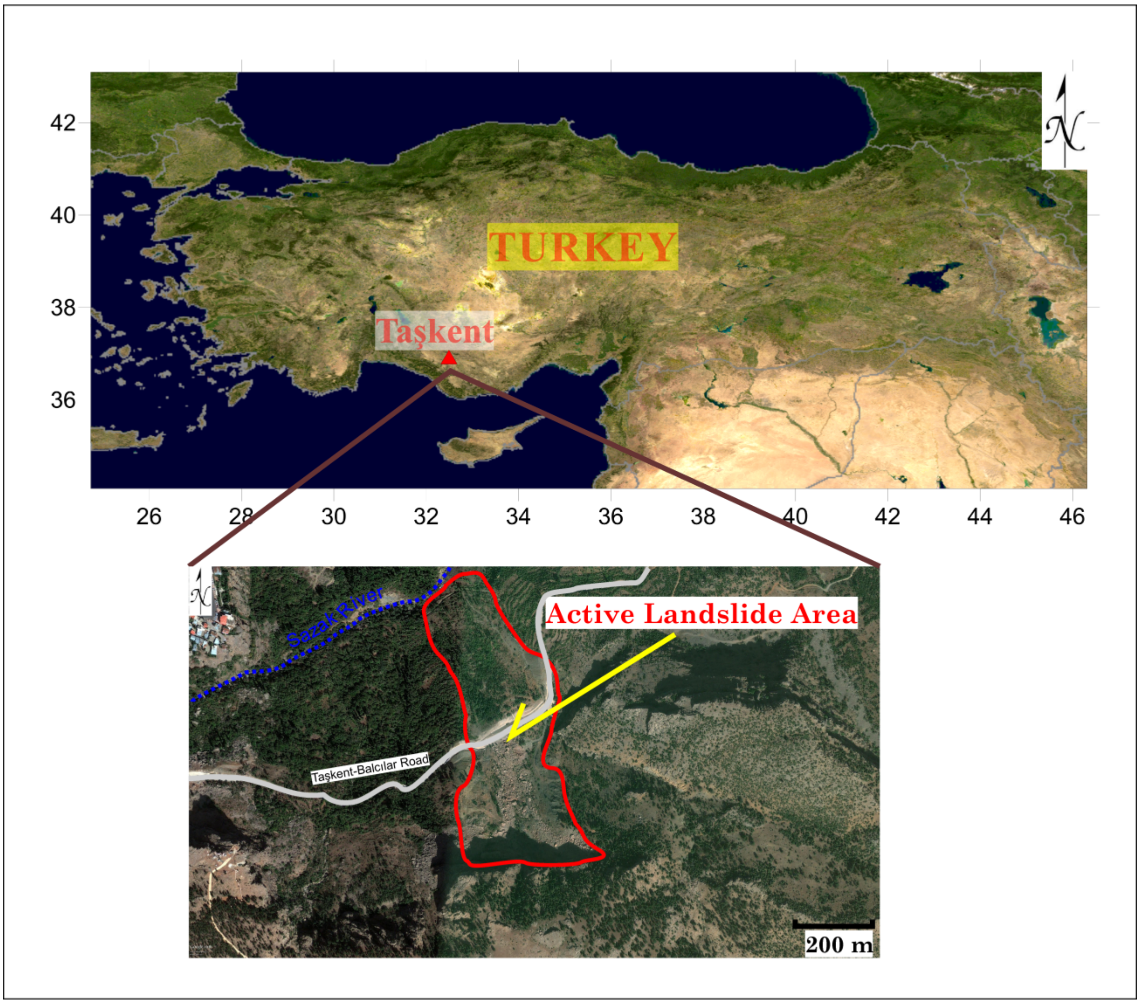

Figure 1. Location of Taşkent and Study Area

2.1 Reference Network

The reference network consists of four reference points that are all built in stable regions outside the landslide area. These points cover 240 ha and are 625 m, 725 m, 1379 m, and 2287 m away from the active landslide area. The GNSS surveys were performed simultaneously with rover GNSS receivers. Reference stations surveyed for eight hours and sampling intervals were set to 10 second and the elevation mask angle was 10^{o}

The reference stations also checked with Turkish Cors-Tr reference frame for stability. The Cors stations were AKSI, KAMN, KNYA, SARV and 65km, 70 km, 121 km and 28 km, from the average of reference station coordinates, respectively. The reference network points can be seen on Figure 2.

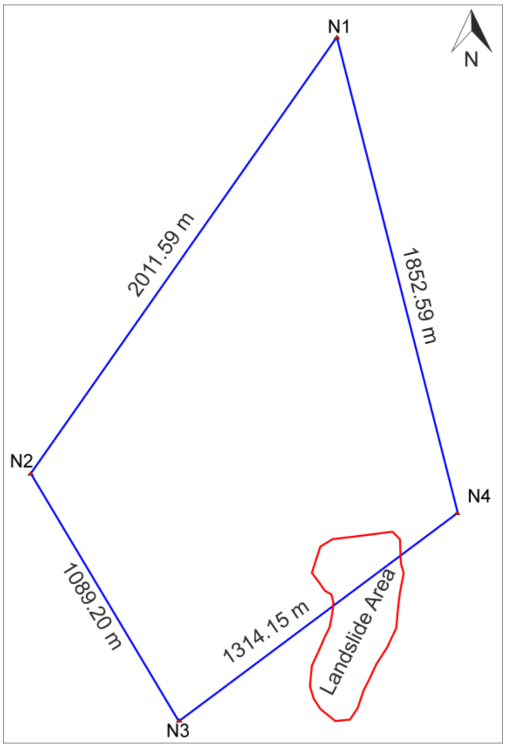

Figure 2. Reference Network and Control point's distances

2.2 Deformation Network

The deformation network of the investigated area covers, in total, four reference stations and thirty-four rover stations. Rover stations distributions were selected to possibly be moved for future and accruable landslide regions. The monitoring network is a multi-temporal GNSS network which is measured periodically.

GNSS surveys were done in 2010 and 2011. The equipment used were Topcon Hiper lite, Javad. These receivers feature a dual frequency carrier phase of GNSS. GNSS observation data was processed using Leica Geo Office software package.

3. MATERIAL AND METHODS

3.1 Minimally Constrained Adjustment of Deformation Network

Prior to making the final adjustment of baseline observations in a network, a minimally constrained least squares adjustment is usually performed. In this adjustment, sometimes called a "free" adjustment, any station in the network may be held fixed with arbitrary coordinates. All other stations in the network are therefore free to adjust as necessary to accommodate the baseline observations and network geometry. The residuals are examined and from them blunders that may have gone undetected through the first set of analyses can be found and eliminated.

In a minimally constrained adjustment, the data needs to satisfy the appropriate geometric closures and are not influenced by control errors. After the adjustment geometric closures, tests can be used to check the priori value of the reference variance against it's a posteriori estimate. But it is sensitive to poor relative weighting. Thus the a posteriori residuals should also be checked for the presence of large discrepancies (Ghilani, 2010).

Detection of outliers in observations can be applied by data snooping and the tau criterion. In this project outliers are detected and removed by tau criterion. Tau statistic value can be computed as

$$\tau_{\alpha/2} = \frac{t_{\alpha/2,r-1\sqrt{r}}}{\sqrt{r-1+t^2_{\alpha/2,r-1}}} \tag{1}$$

Using the tau criterion, observations are considered for rejection when

$$\frac{\left|\overline{v_i}\right|}{S_0} > \tau_{\alpha/2} \tag{2}$$

Here t statistic table value, r-1 degrees of freedom, $\overline{v_i}$ is the standardized residual, S_0 is standard deviation.

The data snooping and tau criterion are theoretically different. However they have similar results in practice. Statistical tests can be chosen as personal preference.

3.2 Statistical Analysis

A static model was used to determine the landslide movements in the deformation network which is measured through multi-temporal GNSS surveys. Least squares method was implanted for solving the model observation of each period. Coordinate vectors of survey points x_1 and x_2, variance-covariance matrices and standard deviations were used to compute the difference between surveys.

Computations were performed as follows,

$$d^i = x^i{}_2 - x^i{}_1 \tag{3}$$

i=1,2,3..n (n) point id in network. The covariance matrix

$$Q_{dd} = Q^1_{xx} + Q^2_{xx} \tag{4}$$

The null hypothesis established as there are no deformation in network

$$H_0 : d = x^i_2 - x^i_1 = 0 \tag{5}$$

θ^2 is the criteria to test null hypothesis,

$$\theta^2 = d^T Q^+ d \tag{6}$$

There Q^+ is the inverse of Q and d^T is transpose of d vectors.

$$F = \frac{\theta^2}{m} \approx F_{n,Dof,\alpha} \tag{7}$$

There m is average of two RMSE (Root Mean Square Errors of first survey and second survey).

F value is compared with F table and if $F_{count} > F_{table}$ then Null hypothesis is rejected, and there is deformation in network, otherwise there is no deformation in the network (Koch, 1999; Niemeier, 1985; Yalçinkaya and Bayrak, 2005).

This method was implemented into the Matlab software by the last author (T. Bayrak). The package has the capability to select which points are mobile which ones are stable.

Defining the deformation vector between two periodic measurements in the global coordinate system (Cartesian coordinates) by $X_{ij} = X_j - X_i$, this vector is defined in the local level system (i.e. ITRF) referenced to the tangent plane at P_i point.

$$n_i = \begin{bmatrix} -\sin\varphi_i \cos\lambda_i \\ -\sin\varphi_i \sin\lambda_i \\ \cos\varphi_i \end{bmatrix} \tag{8}$$

$$e_i = \begin{bmatrix} -\sin\lambda_i \\ \cos\lambda_i \\ 0 \end{bmatrix} \tag{9}$$

$$u_i = \begin{bmatrix} \cos\varphi_i \cos\lambda_i \\ \cos\varphi_i \sin\lambda_i \\ \sin\varphi_i \end{bmatrix} \tag{10}$$

n_i, e_i, u_i axes of the local coordinate system at P_i point the north, east and up direction.

Deformation vector X_{ij} analytically, is achieved by inner products. Assembling the vectors of the local coordinate system as columns in a matrix D_i, i.e.

$$D_i = \begin{bmatrix} -\sin\varphi_i \cos\lambda_i & -\sin\lambda_i & \cos\varphi_i \cos\lambda_i \\ -\sin\varphi_i \sin\lambda_i & \cos\lambda_i & \cos\varphi_i \sin\lambda_i \\ \cos\varphi_i & 0 & \sin\varphi_i \end{bmatrix} \tag{11}$$

x_{ij} can be simplified to

$$x_{ij} = D_i^T \cdot X_{ij} \tag{12}$$

The measurement quantities (distance, azimuth and zenith) can be computed (Hoffmann-Wellenhof et al., 1994).

4. RESULTS

In this research, algorithms in the material and methods sections are applied to analyze the movements between three epochs for the detection of landslide movements in the Taşkent Landslide. For each epoch coordinate, the differences are translated to the local coordinate system in the following table.

Table 1: Landslide Movements between progressive differences on GNSS points

Point Id	2nd-1st Differences (cm)			3rd-2nd Differences (cm)			3rd-1st Differences (cm)		
	North	East	Up	North	East	Up	North	East	Up
1001	16.52	15.61	6.64	13.01	5.61	-11.87	17.34	26.97	-3.03
1002	15.80	14.07	-5.46	15.84	6.83	-4.7	43.45	16.46	-12.61
1003	16.17	14.00	-9.78	17.04	4.44	-6.28	26.47	22.90	-14.46
1004	219.28	96.86	-99.72	61.68	31.09	-39.65	280.95	127.96	-139.37
1005	186.20	95.35	-92.70	56.03	35.77	-37.44	242.23	131.12	-130.14
1006	-0.68	0.39	0.53	0.79	-0.11	-0.17	0.00	0.00	0.00
1007	0.00	0.00	0.00	-18.28	1.66	6.78	-0.54	-0.44	1.04
1008	108.68	12.61	-16.08	36.93	4.64	-9.2	143.26	14.09	-25.86
1009	116.82	68.12	-1.57	44.67	29.8	-0.44	168.01	98.08	-3.39
10010	0.86	0.24	-0.33	-0.87	-0.1	-0.06	0.00	0.00	0.00
10011	33.59	13.94	-15.82	15.95	11.2	-9.45	49.54	25.15	-25.26
10012	32.23	8.75	-10.84	18	4.94	-7.35	49.61	14.72	-18.25
10013	27.20	6.85	-13.28	18.03	1.98	-10.68	43.23	9.51	-23.64
10014	32.30	9.14	-8.25	12.2	5.75	-3.65	46.64	16.74	-13.26
10015	0.00	0.00	0.00	0	0	0	-0.48	-0.19	-0.50
10016	26.56	-0.41	-8.41	20.83	-2.36	-5.7	42.72	-0.52	-12.88
10017	30.58	0.35	-10.31	21.83	-0.61	-7.53	47.03	1.21	-16.51
10018	1.15	-0.70	-2.04	0.39	-0.75	-1.23	1.73	-1.50	-3.25

Point Id	2^{nd}-1^{st} Differences (cm)			3^{rd}-2^{nd} Differences (cm)			3^{rd}-1^{st} Differences (cm)		
	North	East	Up	North	East	Up	North	East	Up
10019	23.06	-9.99	-7.63	20.55	-13.4	-4.3	55.34	-27.46	-15.80
10020	22.31	-7.47	-6.33	20.79	-7.7	-4.88	48.48	-13.08	-11.78
10021	30.00	-5.43	-9.13	23.72	-5.7	-6.03	48.35	-9.50	-13.45
10022	23.01	-7.73	-4.77	15.24	-7.07	-3.67	41.43	-14.00	-9.63
10023	22.77	-5.41	-11.05	20.50	-6.74	-6.39	49.80	-10.43	-18.50
10024	27.38	-5.28	1.61	19.03	-4.68	-0.86	45.89	-6.43	0.92
10025	25.03	-16.43	-4.96	11.80	-14.99	0.08	39.89	-29.80	-5.76
10026	28.79	-17.53	-8.06	14.59	-16.23	-4.97	52.08	-36.10	-15.14
10027	27.59	-18.47	-1.78	17.66	-14.97	0.12	31.03	-25.79	1.62
10028	23.59	-12.09	-6.80	14.49	-11.05	-4.15	47.34	-27.45	-13.41
10029	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10030	-0.04	1.28	-0.10	-0.56	-0.43	-1.88	-0.46	0.87	-2.23
10005	-0.71	0.14	0.83	-0.80	-0.26	-1.52	-1.39	-0.26	-0.97
1111	0.00	0.00	0.00	0.63	-0.53	0.23	0.80	-0.57	0.07
1113	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1114	0.00	0.00	0.00	-17.36	1.81	6.14	-0.03	-0.53	0.59

As a result of statistical analysis, many points show movement inside of the landslide area. The Table 1 shows the results of these movements. Zero values indicate stable points in rover points, and the other values show the displacement for each north, east and up directions. Point movements generally resulted with northern movement. This result can be correlation with slope, aspect, underground waters, distance to river and road. This research will be continued on future projects.

5. CONCLUSIONS

The static deformation model achieved understanding of landslide size by means of GNSS surveys. The implemented statistical method shows us that statistical tests are very useful for the detection of landslides. This method makes it easy to understand deformation in landslide areas. Not only to understand them, but to also tell us a size of movements. A GNSS technique is a well-known technique for deformation monitoring and also gives an idea about landslide deformations. In this paper, the landslide monitoring was performed by statistical tests with the help of GNSS technique.

The GNSS technique and the implemented method achieved good results. However, in landslide monitoring research more information about geological, underground, underwater level and also rainfall informations is required. GNSS results can be integrated with other additional information in order to predict future landslides with estimated models.

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CONTACTS

Mustafa ZEYBEK
Selcuk University Alaeddin Keykubat Campus
Engineering Faculty, Department of Geomatics
Selçuklu/Konya
TURKEY
Tel. +903322231897
Fax +
Email:mzeybek@selcuk.edu.tr
Web site:

[1]Selcuk University, Engineering Faculty, Geomatics Department, Selcuklu/Konya, TURKEY

[2] Selcuk University, Engineering Faculty, Geology Department, Selcuklu/Konya, TURKEY

[3]Gümüşhane University, Engineering Faculty, Geomatics Department, Gümüşhane, TURKEY